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Liquid Propellant Gas Generation Systems

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1. SCOPE:

This information report presents a preliminary discussion of liquid propellant gas generation (LPGG) systems. A LPGG system, as used herein, is defined as a system which stores a liquid propellant and, on command, discharges and converts the liquid propellant to a gas. The LPGG system can interface with a gas-to-mechanical energy conversion device to make up an auxiliary power system. Figure 1 shows a block diagram of LPGG system components which include a propellant tank, propellant expulsion system, propellant control and a decomposition (or combustion) chamber.

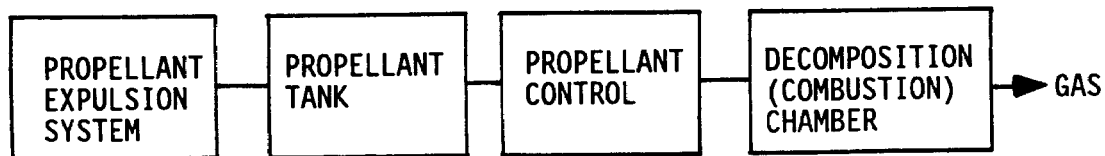


FIGURE 1 - LPGG System Block Diagram

The purpose of this report is to provide general information on the variety of components and system arrangements which can be considered in LPGG design, summarize advantages and disadvantages of various approaches and provide basic sizing methods suitable for initial tradeoff purposes.

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3. SYSTEM CONSIDERATIONS:

Liquid propellant gas generator (LPGG) systems are suitable for a wide variety of auxiliary power supply applications, particularly those requiring a variable duty cycle, long duration and/or reuse. Through use of liquid flow control devices (on-off or proportional valves) power output of the LPGG can be varied over a wide range resulting in efficient usage of propellant. This load-following capability is a primary advantage of LPGG systems.

Alternates to LPGG systems are discussed in AIR744. This report presents a summary of equipment used and the experience gained with various types of power sources for use in auxiliary power systems for aerospace applications.

The following types of auxiliary power systems are typically powered with LPGG systems.

- a. Turbine machinery supplying electrical, hydraulic, pneumatic and/or shaft power.
- b. Positive displacement engines supplying electrical, hydraulic, pneumatic and/or shaft power.
- c. High pressure warm gas sources supplying a variety of piston type actuators for rocket engine thrust vector control or aerodynamic control surface positioning.
- d. High pressure warm gas sources for pressurization of rocket engines propellant tank.
- e. Power source for driving propellant feed pumps for the vehicle's main propulsion engines.
- f. Attitude reaction controls.
- g. Warm gas source for fluidic devices and fluidic computation systems.

The way the LPGG will be used in the system and the characteristics of the particular system will impact the LPGG design. The following variables should be defined and considered in the design:

- a. Duration of active life
- b. Duty cycle
- c. Storage life
- d. Power level
- e. Type of power (pressure-flow, electrical, moment, etc.)
- f. Power density
- g. Environment (temperature, space, nuclear, etc.)
- h. Check-out requirements
- i. Response (activation time and operating dynamics)
- j. Safety
- k. Cost
- l. Reliability
- m. Interfaces and limitations
- n. Maximum exhaust gas temperature
- o. Exhaust gas composition constraints

4. LIQUID PROPELLANTS:

4.1 Monopropellants:

A monopropellant is a liquid capable of undergoing an exothermic reaction (decomposition), releasing energy in the form of hot gases. This reaction can be initiated by the application of heat or contact with a catalytic or hyperbolic substance.

Monopropellants have the advantage of controllability and packaging flexibility when compared to solid propellants, and lack of complexity when compared to bipropellant systems. A number of monopropellants have been developed, and are available to meet a variety of specific system requirements. Hydrogen peroxide, Otto fuel, ethylene oxide, and various hydrazine blends are well known and a wealth of engineering data is available. Specific system and operational requirements dictate the choice of the particular monopropellant. For example, a requirement for extended sealed storage life could remove hydrogen peroxide from consideration since hydrogen peroxide slowly decomposes. On the other hand, where fuel is being consumed over an extended period of time, as in a satellite application, hydrogen peroxide has demonstrated reliable operation in a sealed system for a period of more than three years. A low temperature operating requirement may also eliminate some of the hydrazine blends and Otto Fuel.

See Table 1 for properties of various monopropellants. Additional information on monopropellants can be obtained from the references listed in the final section of this standard.

Hydrazine and hydrazine blend monopropellants have received considerable attention in recent years due to their storability, high energy release cleanliness of exhaust, and moderate cost; however, the possible toxicity of liquid hydrazine is a potential problem.

TABLE 1 - Monopropellant Characteristics
Viscosity, 77 °F (25 °C)

	Chemical Formula	Ethylene Oxide	N-Propyl Nitrate	Otto Fuel II	Anhydrous Hydrazine	Typical Alkylated Hydrazine Blends	Typical Nitrated Hydrazine Blends	Hydrogen Peroxide 90%
	C_2H_6O		$C_3H_7NO_3$	Classified	N_2H_4	$CH_3N_2H_3$, N_2H_4	$CH_3N_2H_3$, N_2H_4 , $N_2H_5NO_3$	H_2O_2
Specific Gravity 77 °F (25 °C)	0.870		1.050	1.234	1.004	0.900	0.950	1.380
Viscosity, 77 °F (25 °C), cs	0.24		0.65	3.80	0.905	1.10	1.70	1.05
Freezing Pt., °F (°C)	-171 (-113)		-150 (100)	-24.8 (31.5)	34.7 (1.5)	-68 (-54)	-68 (-54)	12 (-11)
Vapor Pressure, 77 °F, psia (25 °C, kPa)	26 (179)		0.510 (3.52)	.002 (.014)	0.278 (1.92)	0.90 (6.21)	0.84 (5.79)	0.10 (.69)
Flash Pt., °F (°C)	<0 (-18)		65 (18)	235 (113)	126 (52)	80 (26)	85 (29)	>230 (110)
Gas Hp. h/lb. (kJ h/kg)	.248 (147)		.293 (173)	.337 (200)	.375 (50% NH_3 Disso.) (222)	.312 (185)	.341 (202)	.137 (81)
Avg. Mole. Weight	20.7		16.8	21.7	13.8	12.8	13.0	22.1
Gas Temp., °F (°C)	1740 (949)		2190 (1199)	2150 (1176)	1800 (982)	1340 (726)	1500 (815)	1380 (748)
Material Compatibility	Very Good	Very Good	Good	Very Good	Good	Good	Good	Poor
Storability	Very Good	Very Good	Good	Very good	Good	Good	Good	Poor
Fire Hazard	High	High	Medium	Very Low	Low	Low	Low	Med./Low
Toxicity	Low	Low	Low	Very Low	Medium	Medium	Medium	Low
Decomposition Products	C, CH_4 , $C_2H_4CO_2$, O_2 , CO, H_2	C, CO, H_2 , N_2CO_2 , CH_4 , H_2O	C, CO, H_2 , N_2CO_2 , CH_4 , H_2O	C, CO, C_2H_6CO , N_2 , H_2 , CHN, H_2O , NO	N_2 , H_2NH_3	N_2 , H_2 , C, CH_4	N_2 , H_2 , C, CH_4 , H_2O Trace CO	H_2O , O_2
Comments	High Carbon Content in Exhaust	Exhibits Diesel Tendency	Exhibits Diesel Tendency	Exhibits Diesel Tendency	High Freezing Point	High Carbon Content in Exhaust	Nitrates Decrease Storability at high temperatures	Requires Venting with limited storability

4.1 (Continued):

Anhydrous hydrazine (N_2H_4) is a commonly used monopropellant in aerospace applications. This monopropellant exemplifies all of the advantages listed in the above paragraph, and in addition it is readily decomposed upon contact with a spontaneous catalyst such as Shell 405. The major restriction to use of anhydrous hydrazine is its freezing point of approximately 34 °F (1 °C).

The environmental requirements in many applications, therefore, eliminate the use of anhydrous hydrazine. To meet these requirements, a freezing point depressant is added to the hydrazine. These depressants include water, monomethyl hydrazine and hydrazine nitrate. Typical fuels with depressed freezing points, which contain these additives are Mixed Hydrazine Fuels (MHF) such as MHF-3, MHF-5 and Monopropellant Gas Generator Propellants (MGGP) such as MGGP-1, and hydrazine-water mixtures. The freezing point of hydrazine can be depressed to near -65 °F (-54 °C) by the addition of approximately 30% water. Figure 2 shows the freezing point as a function of water content. Hydrazine energy content decreases with water addition. As an example, a 70% hydrazine, 30% water blend has less than 65% of the available energy (BTU/lb) (J/kg) of undiluted anhydrous hydrazine. Table 2 shows constituents of various hydrazine blends with depressed freezing points and Table 3 shows their physical and chemical properties.

MHF-3 and MHF-5 both contain monomethyl hydrazine, a carbon containing compound. These carbon containing compounds normally cannot be used with catalytic decomposition systems since the catalyst surface quickly becomes coated with carbon and is rendered useless for further reactivity with incoming propellant. MGGP-1 and hydrazine-water mixtures can be used with catalytic decomposition chambers. All of the above mentioned fuels can be used in a thermal type chamber.

Storability, energy content, material compatibility, and safety become the parameters used in selecting a fuel for a particular application. The Monopropellant blends which contain either hydrazine nitrate or hydrazine azide exhibit high energy levels and good reactivity, however, they have limited storage capability at elevated temperatures, as determined by measuring pressure rise in a sealed propellant tank. Pressure rise rates of the nitrate and azide blends are high compared to monomethylhydrazine blends such as MHF-3 or water-hydrazine blends. MHF-5 is a high nitrate content blend and MGGP-1 and 70/20/10 are moderate nitrate content blends.

As a general guideline for this document, "long-term storage" is measured in years. Typical monopropellant and pressurization system tankage storage requirement for aircraft emergency power units is three years. Reference to "short-term storage" generally relates to months. Short-term storage capability is adequate for many launch and space vehicle applications where propellant loading is done just before launch and tank storage time requirements during the mission are short.

Most of the published data of propellant capability for long-term storage are in the 100 to 165 °F (38 to 74 °C) range. Decomposition of mixed hydrazine fuels is temperature dependent. The higher the temperature, the higher the rate of fuel decomposition. Also, it has been shown that the mixed hydrazine fuels do not attain a constant slope for pressure rise rate until approximately 60 days.

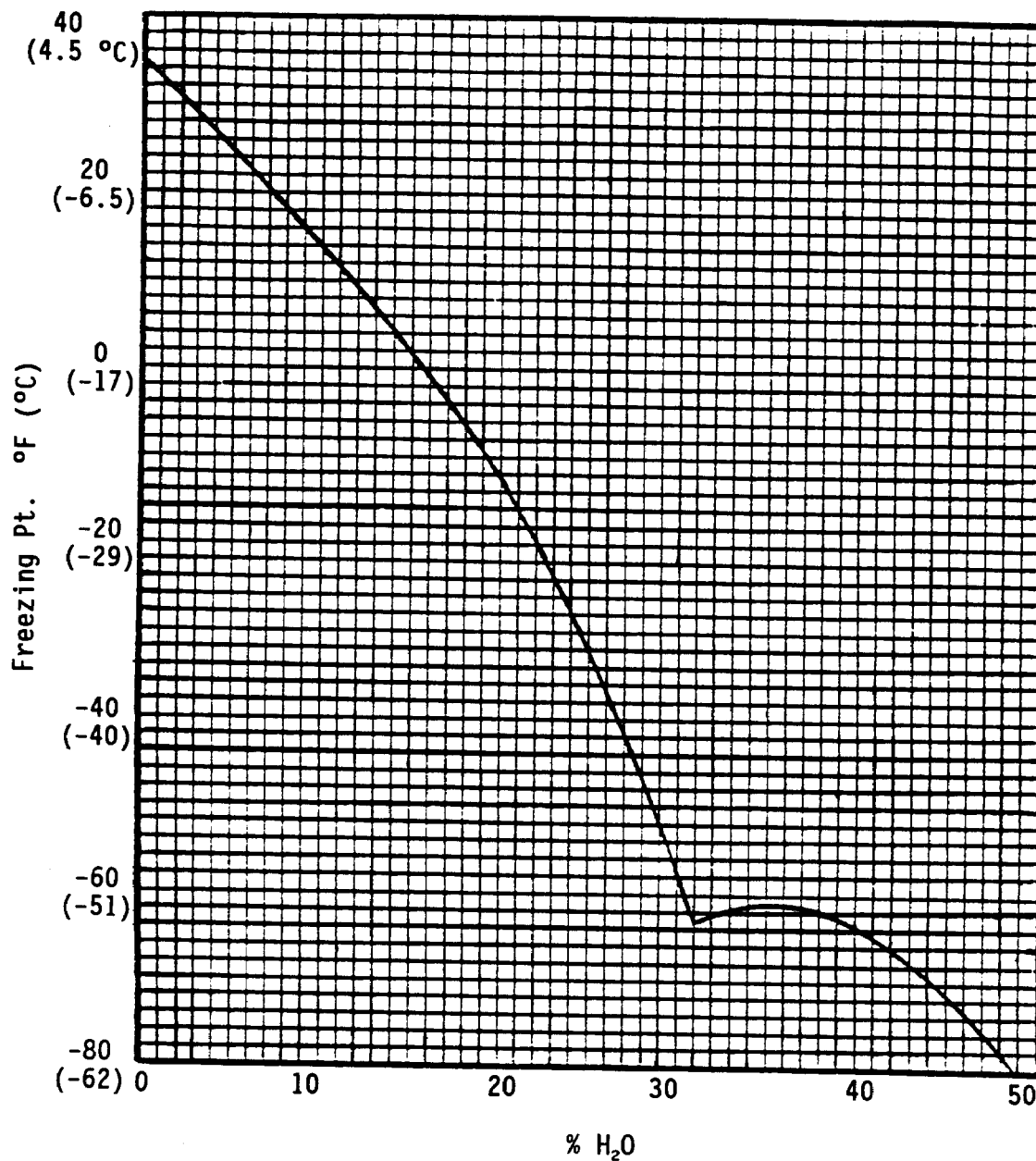
FIGURE 2 - Freezing Point Versus Percent H_2O in N_2H_4/H_2O Blend

TABLE 2 - Constituents of Hydrazine Blends With Depressed Freezing Points

Fuel	Hydrazine N ₂ H ₄	Water H ₂ O	Hydrazine Nitrate N ₂ H ₄ HNO ₃	Monomethyl Hydrazine MMH
Hydrazine	X			
MHF-3	X			X
70-20-10	X		X	X
MGGP-1	X	X	X	
N ₂ H ₄ /H ₂ O	X	X		

TABLE 3 - Physical and Chemical Properties of Hydrazine Monopropellants

Percent H ₂ O	Hydrazine 0	Hydrazine 10	Hydrazine 20	Hydrazine 30	70-20-10	MHF-3	MHF-5	MGGP-1
Freezing Point °F (°C)	34.7 (1.5)	14 (-10)	-12 (-11)	-58 (-54)	-68 (-54)	-68 (-54)	-44 (-42)	-68 (-54)
Boiling Point °F (°C)	238 (114)	243 (117)	247 (119)	248 (120)	200 (93)	194 (90)	207 (97)	237.1 (114)
SP Gravity at 77 °F (25 °C)	1.004	1.01	1.02	1.026	.95	.894	1.011	1.06
Vapor Pressure psia at 77 °F (kPa at 25 °C)	.28 (1.93)	0.308 (2.12)	0.33 (2.28)	.354 (2.44)	0.84 (5.79)	1.0 (6.90)	0.77 (5.31)	0.15 (1.03)
Viscosity (CS) at 77 °F (25 °C)	0.9	1.1	1.5	1.65	1.32	1.0	1.9	1.9
0 °F (-17 °C)	--	--	5.2	5.5	5.0	3.0	7.0	7.4
-40 °F (-40 °C)	--	--	--	18.0	13.6	9.0	30.0	25.0
-64 °F (-53 °C)	--	--	--	32.5	68	29	100.0	90.0
Ignition Temp. °F (°C)	518 (270)	--	--	--	530 (276)	520 (271)	500 (260)	--
Flashpoint °F (°C)	126 (52)	134 (57)	143 (62)	154 (68)	90 (32)	80 (27)	90 (32)	--

4.1 (Continued):

Reports have been published (2.1 and 2.2) on storage tests of mixed hydrazine fuels at temperatures of 100 to 160 °F (38 to 74 °C) in laboratory and field experiments while in contact with various tankage materials. MHF-3 was shown to be storable for three years or more in 1100, 2024, and 6061 aluminum, 304 stainless and Ti-6Al-4V alloys, although analysis of the fuel blends, prior to and after storage, ascertained that some fuel decomposition occurred in all storage containers.

Figure 3 shows elevated temperature long-term storage data for MHF-3 and 70-20-10. Five year storage appears practical with either of these fuels. Storage data on MHF-5 and MGGP-1 are also shown.

NOTES:

1. MHF-3 @ 160 °F (71 °C); 1100 Al Container; 10% Ullage
2. 70-20-10 @ 160 °F (71 °C); 1100 Al Container; 10% Ullage
3. MGGP-1 @ 165 °F (74 °C); 1100 Al Container; 48% Ullage
4. MHF-5 @ 165 °F (74 °C); Al Container; 10% Ullage

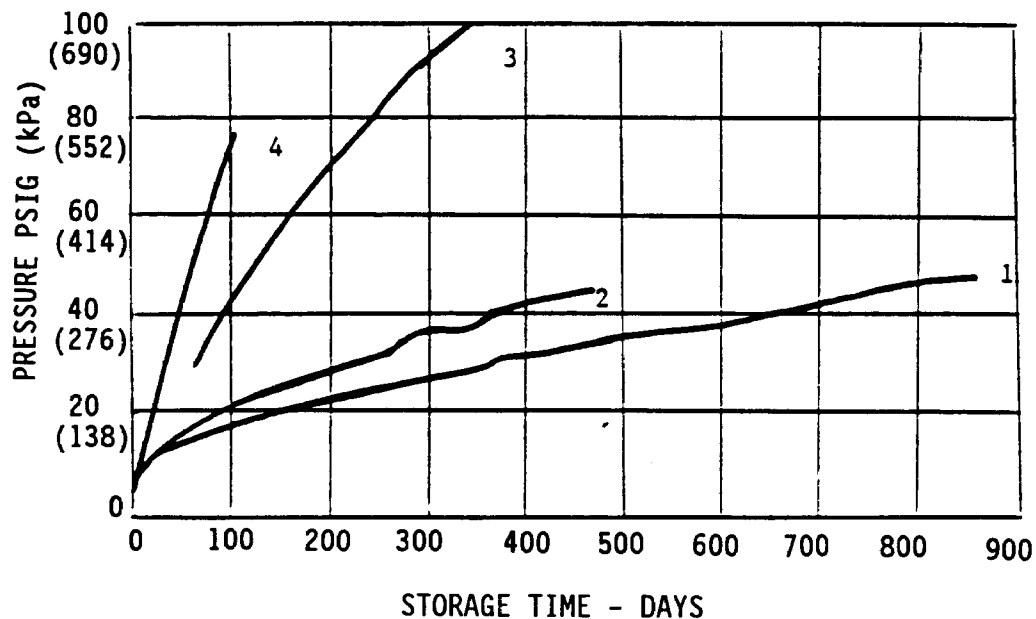


FIGURE 3 - Storage Data on Hydrazine Blends

4.2 Bipropellants:

A bipropellant system uses a fuel and an oxidizer, which when mixed, undergo an exothermic reaction (combustion), releasing energy in the form of hot gases. Ignition of the fuel and oxidizer mixture can be hyperbolic (spontaneous combustion upon contact), catalytic or promoted through application of a heat source.

Bipropellants used in auxiliary power systems are normally the same as those used by the vehicle's main propulsion or attitude control systems. The performance potential of bipropellants is generally higher than that of monopropellants; but, gas temperatures at the peak performance mixture ratio are much too high for conventional power conversion equipment. For this reason, fuel-rich mixtures are generally used. A vast amount of engineering data is readily available on bipropellant characteristics and specific design requirements. Table 4 illustrates physical and energy characteristics for a few typical propellants. Additional information on bipropellants can be obtained from the references listed in the final section of this standard.

4.3 Safety and Handling:

The safety and handling requirements for the various fuels, oxidizers and monopropellants must be considered and these requirements are an important part of any tradeoff study for system selection. Tables 1 and 4 include basic handling and storage information. Each of the candidate fuels, oxidizers and monopropellants have unique flammability, explosive hazard and toxicity characteristics which must be understood and considered in the selection process. A good reference document for safety and handling information is 2.13. The volume includes descriptions of properties, hazards, safety measures, materials and equipment for transfer and storage, main storage and ready storage, systems and equipment cleaning, transfer operations, transportation, emergency procedures and disposal. This document can be obtained from the Chemical Propulsion Information Agency (CPIA), John Hopkins University/APL, 11100 John Hopkins Road, Laurel, Maryland 20810.

In addition, the Department of Transportation of the U.S. Government has detailed extensive regulations related to hazardous materials. These regulations are published in the "Code of Federal Regulations 49, Transportation" in two volumes; parts 1 to 99 and parts 100 to 199. These regulations cover the propellant and pressure containers. The volumes are obtainable through the Superintendent of Documents, Washington, D.C.

5. PROPELLANT TANKS:

The propellant tank provides two functions: storage of the LPGG propellant and fuel expulsion during LPGG operation. The storage function necessitates use of tankage materials that are compatible with the LPGG propellant for a duration required by the specific application. The expulsion function is provided with either a positive expulsion device, or by direct propellant pressurization.